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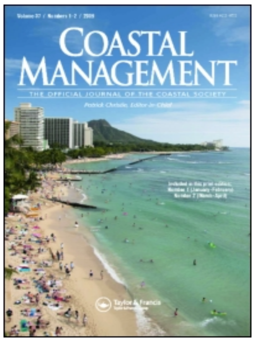

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Ballast Water Risk Indication for the North Sea

Ruurd van der Meer[a,b], M. Karin de Boer[c,d], Viola Liebich[e], Cato ten Hallers[f], Marcel Veldhuis[g], and Karin Ree[c]

[a]IVEM Center for Energy and Environmental Sciences, ESRIG, University of Groningen, Groningen, the Netherlands; [b]MIWB Dutch Maritime University of Applied Sciences, NHL University of Applied Sciences, Leeuwarden, the Netherlands; [c]Beta Science Shop, Science and Society Group, ESRIG, University of Groningen, Groningen, the Netherlands; [d]Ocean Ecosystems, ESRIG, University of Groningen, Groningen, the Netherlands; [e]NIOZ Royal Netherlands Institute for Sea Research, Den Burg, Texel, the Netherlands; [f]Cato Marine Ecosystems, Kantens, the Netherlands; [g]MEA-NL Marine Eco-Analytics, Den Oever, the Netherlands

ABSTRACT

The ballast water from ships carries marine organisms that have invasive potential. The International Maritime Organization Ballast Water Management Convention (2004) requires ballast water exchange or ballast water management (BWM) systems either onboard or ashore. Ships can be exempted on the basis of risk assessment, when exclusively sailing between specific ports or in an enclosed area. In reply to our questionnaire, the shipping sector argues that the North Sea is ecologically homogeneous and exemptions could therefore be granted. This paper proposes that the North Sea area is, in fact, not homogeneous in terms of hydrographical and biological conditions; therefore, ballast water is a relevant transport mechanism for organisms. Within the North Sea, the short shipping routes indicate a high risk for survival. We examined actual simulation models for ballast water risk assessment in the North Sea, and we have identified the major parameters that need to be included in such models. These models provided a basis; they further need to be combined and adapted for the purpose of evaluating the rationale for an exemption. We concluded that exemptions from BWM are not recommended for the North Sea area. Anticipating the Ballast Water Management Convention, ship owners might do well to study possibilities for installing BWM systems onboard.

KEYWORDS
ballast water management; non-indigenous species; North Sea; risk assessment

Introduction

Marine invasions

Merchant shipping is a major source of unintentional introduction of species in marine ecosystems (Carlton and Geller 1993). Ships translocate organisms around the world by means of hull fouling and onboard ballast water (Gollasch 2002). Ballast water is required in order to enhance stability and hydrodynamic sailing characteristics (Clark 2002; Van Dokkum 2003). The estimation of ballast water discharges worldwide is 3.1 billion tons for 2013

CONTACT Karin Ree C.M.Ree@rug.nl Beta Science Shop, Science and Society Group, ESRIG, University of Groningen, Nijenborgh 6, 9747 AG, Groningen, the Netherlands.

(David 2015). As many as 7000 species (Carlton 1999) are transferred this way around the globe. A variety of species can survive in ballast water tanks for several days (Gollasch et al. 2000; Flagella et al. 2007) and so will be discharged in the port of destination.

Once established, populations of non-indigenous species are at risk of becoming invasive in marine and estuarine habitats, with adverse impacts on ecology, the economy, and human health (Anil et al. 2002; Lovell, Stone, and Fernandez 2006). Invasions of non-indigenous species have been shown to affect biodiversity and ecosystem functions (Stachowicz, Bruno, and Emmett Duffy 2007). The costs to fisheries and industries are significant (Kideys 1994). The introduction of pathogenic viruses and bacteria by means of ballast water poses a threat to human health (Dahlstrom, Hewitt, and Campbell 2011).

Ballast Water Management Convention

The International Maritime Organization (IMO) adopted the Ballast Water Management Convention (BWMC) to prevent, minimize, and ultimately eliminate the transfer of harmful aquatic organisms and pathogens through the control and management of ships' ballast water and sediments (IMO 2004).

The BWMC requires BWM in the recipient port or onboard ships in order to reduce the number of viable organisms in the ballast water discharge, according to the Regulation D-2 Ballast Water Performance Standard (IMO 2004). Management can be performed by ballast water exchange (BWE) during the voyage, and by chemical or physical disinfection by BWM systems to remove or kill the organisms (IMO 2004).

The BWMC will come into force 12 months after ratification by a minimum of 30 IMO member states, covering 35% of world gross tonnage (IMO 2004). To date, the total number of contracting states has reached 44 states and 32.86% of the gross tonnage of the world's merchant shipping (IMO 2015a). It is expected that the convention will come into force in 2016, or soon thereafter (BIMCO 2014).

BWE is an intermediate option, which will be phased out after the BWMC has come into force. According to the Regulation D-1 Ballast Water Exchange Standard, BWE is only allowed in water at least 200 m in depth and at least 200 nautical miles from the nearest land or, in case of a coastal voyage, at least 50 nautical miles offshore (IMO 2004). For vessels on a coastal voyage in areas that do not meet these requirements, the port state may designate locations for BWE (Regulation B-4 2, IMO 2004).

The Ballast Water Performance Standard of Regulation D-2 can be achieved by means of BWM systems. BWM systems are designed to remove, kill, or inactivate organisms in ballast water prior to discharge. Several systems have been developed as BWM options (Tsolaki and Diamadopoulos 2010). The dominant systems combine removal by filtering, or hydrocyclonage, with physical or chemical disinfection. Physical disinfection includes UV irradiation. Oxidizing agents for chemical disinfection include chlorine, ozone, and hydrogen peroxide (Balaji and Yaakob 2011). All BWM systems require approval by the authorities of the certifying state. Through to October 2014, 51 systems have been approved by these authorities, and 50 BWM systems have received Basic and 36 Final Approval from IMO (2014).

Only a few ships out of more than 50,000 ships that need to be in compliance in the near future have actually planned or installed BWM systems. There is hardly any data available, however, concerning the onboard performance of BWM systems in practice. Experience is restricted to the findings of shipboard certification tests. Retrofitting of older ships, especially, has several drawbacks: cost and availability of equipment, cost of installation, lack of space onboard, maintenance requirements, and availability of docking capacity (Gregg, Rigby, and Hallegraeff 2009). It is generally considered that there is insufficient time to retrofit the fleet before the BWMC deadline.

Ballast water management exemptions

The BWMC offers an opportunity for exemption from the BWE/BWM requirements, by providing ships with a waiver from installing BWM systems onboard. Exemptions are granted solely to those ships sailing exclusively between specified ports within a biogeographical region with similar environmental conditions. The exemptions are granted by the IMO member states, in whose waters the ships operate. Duration of an exemption is limited to a maximum of five years subject to intermediate review (IMO 2004). The foundation for exemptions is Regulation A-4 of the BWMC; the required risk assessment must be performed in accordance with the G-7 Guidelines for Risk Assessment (IMO 2007).

The present study will focus on the center of shipping routes in Western Europe, the North Sea. Is an exemption from the BWE/BWM requirements appropriate and permissible in this area?

North Sea exemptions

Several vessels operate exclusively within the North Sea area, such as ferries, vessels engaged in short-sea trading, and fishing vessels (European Commission 2014). The North Sea is a semi-enclosed and shallow sea (Table 1 and Figure 1). Water depth and distances to shore are below the BWMC minimum limits for BWE. Therefore, BWE requirements cannot be met, except for a limited area in the northern North Sea, part of the Norwegian Trench (Figure 1; Gollasch, David and Leppäkoski 2011). Moreover, sailing distances between North Sea ports are often too short to perform a proper BWE during the voyage (Table 2). As a compromise, the nations

Table 1. Location and salinity of the major North Sea ports (AAPA World Port Rankings 2010).

Major port in North Sea area (number in figures)	Cargo transshipment (metric tons)	Container transshipment (TEU)	Estuary/river	Mean water salinity (psu)
(1) Tees and Hartlepool	35,697,000	<550,000	Tees Estuary	27.5
(2) Grimsby and Immingham	54,029,000	<550,000	Humber Estuary	23.5 (in docks)
(3) Felixstowe	25,756,000	**3,400,000**	Orwell and Stour Estuary	33.5
(4) London	48,060,000	<550,000	Thames River	Wide range of salinities
(5) Dunkirk	42,980,000	<550,000	Sea linked to various canals	33.5
(6) Zeebrugge	49,600,000	2,389,879	Sea linked to Boldwin Canal	26–27.5 (in docks)
(7) Antwerp	**178,167,000**	**8,468,475**	Scheldt River	7.5 (in docks)*
(8) Rotterdam	**429,926,000**	**11,145,804**	Rhine Estuary	17–33.5
(9) Amsterdam	**90,644,000**	<550,000	IJ	Fresh
(10) Bremerhaven	**68,690,000**	**4,888,655**	Weser Estuary	12–15.5
(11) Hamburg	**121,187,000**	**7,895,736**	Elbe River	1
(12) Gothenburg	43,875,000	879,611	Göta älv Estuary	17
(13) Bergen	49,870,000	<550,000	Sea (fjord)	33.5

Notes. The sizes of the ports are represented as a function of the volume of annual cargo and container trans-shipment. The ports are ordered according to counterclockwise residual current. Salinity data are from the British Admiralty (2009–2011) except for * (Shipping Guides 2010). Bold numbers indicate that the port is one of the top five ports of the North Sea area in terms of cargo.

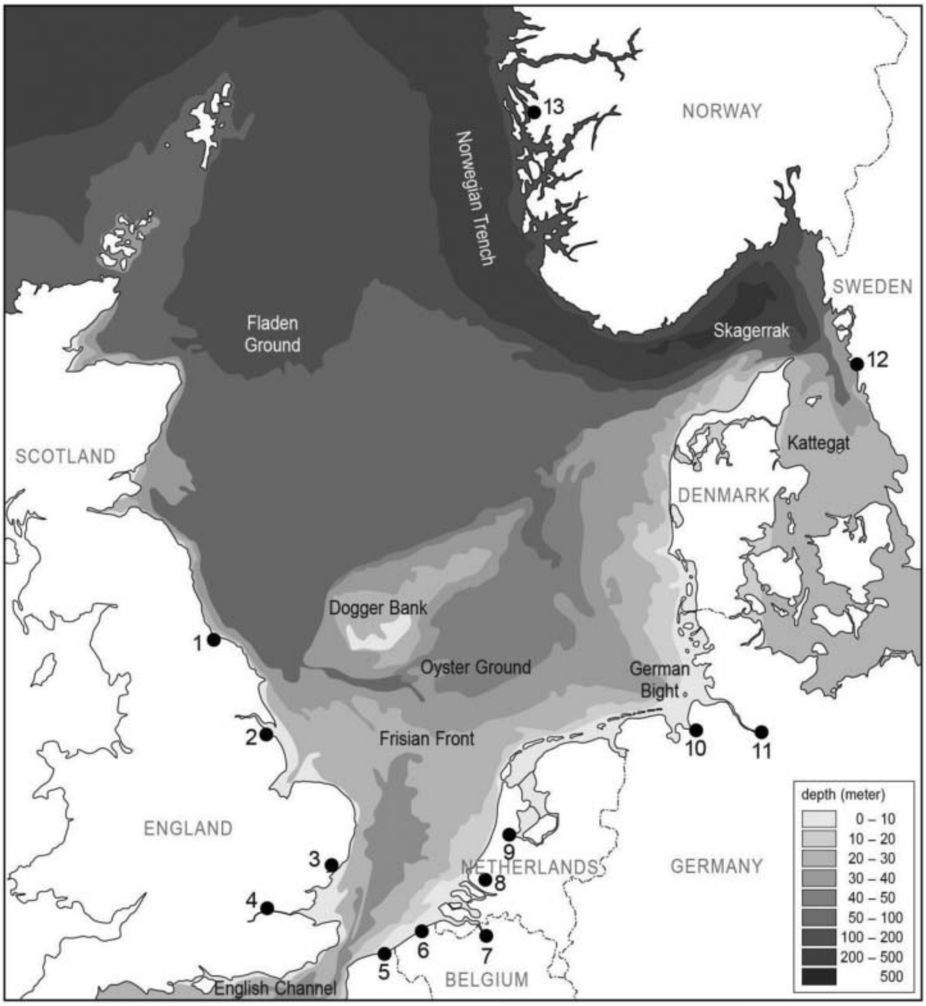

Figure 1. An overview of the North Sea bathymetry, northwestern Europe (from ICONA 1992). The dark dots are the major North Sea ports. The numbers correspond to the numbers in Table 1.

bordering the North Sea are proposing exchange areas for intra North Sea voyages throughout the entire North Sea area, except for coastal and protected areas (IMO 2015b).

The North Sea is regarded as an area in which the impact from the introduction of non-indigenous species is high (Vila et al. 2010). Over 150 non-indigenous species have been identified in the North Sea area (Gollasch et al. 2009). Most of the ports where ballast water is taken in or released are located in North Sea estuaries and river mouths (Table 1 and Figure 1; Nehring 2006; Reise, Gollasch, and Wolff 1999). North Sea estuaries are considered to be highly susceptible to the introduction of new species, due to a combination of intensive international shipping traffic and ports situated in areas with a wide range of salinity (Table 1 and Figure 2; Nehring 2006). Their ecological value is recognized in Natura 2000's international conservation regulations (EEA 2012), Marine Protective Areas (OSPAR 2013), and Particularly Sensitive Sea Areas (IMO 2013).

Table 2. Sailing times in hours between the major ports in the North Sea, based on a speed-over-ground of 10 knots.

	Tees and Hartlepool	Grimsby	Felixstowe	London	Dunkirk	Zeebrugge	Antwerp	Rotterdam	Amsterdam	Bremerhaven	Hamburg	Gothenburg
Grimsby	10											
Felixstowe	22	15										
London	29	22	8									
Dunkirk	29	21	8	11								
Zeebrugge	27	20	8	12	8							
Antwerp	33	26	14	20	15	9						
Rotterdam	27	20	12	19	14	9	15					
Amsterdam	26	20	14	21	17	13	18	7				
Bremerhaven	36	32	31	38	35	29	36	26	23			
Hamburg	41	37	36	43	39	35	41	31	27	12		
Gothenburg	48	49	52	60	59	54	60	50	47	37	33	
Bergen	41	46	54	61	59	58	64	54	51	45	49	35

Note. The longest sailing times are those between Norway (Bergen) and the southern North Sea (Antwerp). They are all below the 3-day (72-h) threshold, at which most organisms in ballast water die (Sea-distances.org 2015).

The chance of acquiring a BWM exemption is of interest to the shipping industry in order to circumvent the cost of installing, operating, and maintaining a BWM system. We distributed a questionnaire among operators in the North Sea shipping industry. The questionnaire investigated the level of awareness of the shipping sector vis-à-vis mitigation measures featured in the BWMC, as well as their expectations as to the likelihood of obtaining BWM exemptions for ships in the North Sea area. Thirteen companies, mainly Dutch ones, responded to the questionnaire (Appendix A). These companies represent many different types of vessels (ferries, cruise vessels, oil carriers, containers, etc.). Twelve companies have vessels that frequently take in ballast water, and four of the companies have vessels that operate exclusively within the North Sea (from 30% to 100% of their fleet).

The response showed that all companies are aware of the BWMC regulations, and a majority of them have prepared a BWM strategy. As for ships in the North Sea area, nearly all companies

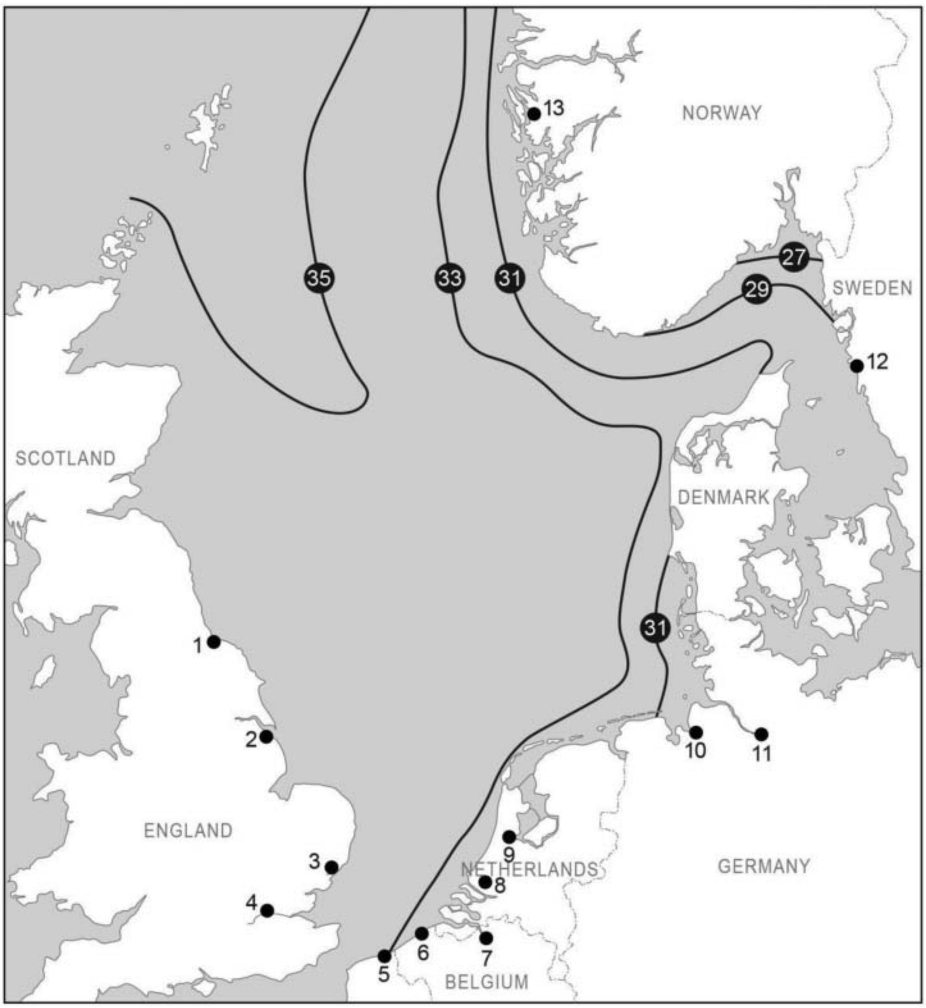

Figure 2. The salinity of the North Sea during August (from Van Aaken 1990). The numbered dots with lines show the boundary of the salinity (psu). The dark dots are the major North Sea ports. The numbers correspond to the numbers in Table 1.

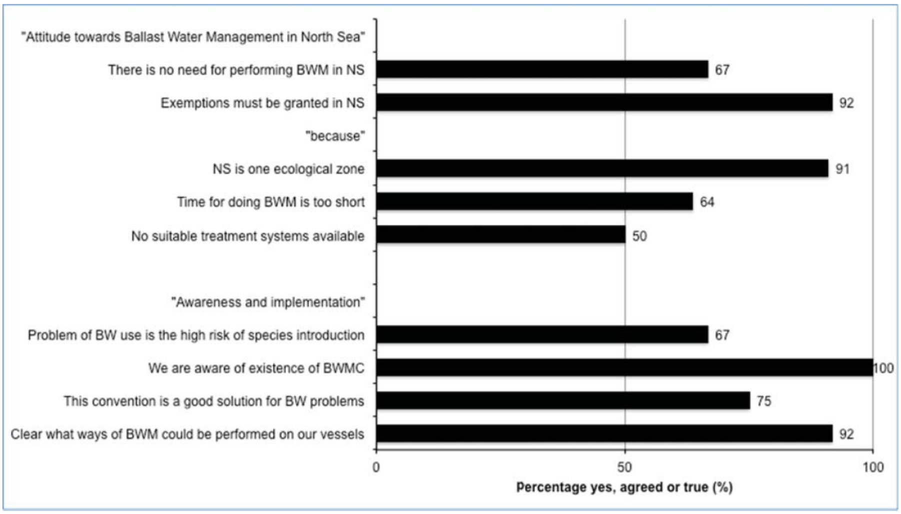

Figure 3. Attitude of ship companies toward ballast water management (BWM) exemptions in the North Sea area (NS). Thirteen companies responded to the questionnaire; twelve of these companies have ships that frequently take in ballast water (Appendix A). BW, ballast water; BWMC, Ballast Water Management Convention.

expect that exemptions will be granted (92%), based on the assumption that the entire region can be considered as an ecologically homogeneous zone (91%; Figure 3). This assumption is based on the view that organisms can be transported throughout the area by means of natural processes, such as currents, without encountering any environmental barrier to their ability to establish. Ballast water is not unique as a transport mechanism in the North Sea area, in other words. As a consequence, species are therefore able to be distributed evenly across the area.

Strategies for issuing exemptions from the BWM requirements have been investigated for the Baltic and North Sea areas (Behrens, Leppäkoski, and Olenin 2005; Gollasch and Leppäkoski 2007). Implementation of the strategy in the North Sea area is in the process of preparation. The member countries of Oslo Paris convention (OSPAR) and Helsinki commission (HELCOM) (North Sea and Baltic states) are preparing a harmonized procedure for risk assessment (Helsinki and OSPAR Commission 2014). Under the HELCOM/OSPAR Harmonized Procedure, an online risk assessment tool is available for administrations and ship owners to identify routes that may qualify for exemptions (HELCOM/OSPAR Harmonized Procedure 2014). The key risk criteria are limited to the difference in water salinity between the ports that are visited and the presence of target species in the donor port (Helsinki and OSPAR Commissions 2014).

With reference to the questionnaire, we evaluated the permissibility of BWM exemptions for ships operating in the North Sea area only, based on the key factors for introducing an aquatic species. We will then go on to discuss models to assess the risk of the translocation of ballast water on various shipping routes in the North Sea area.

Risk assessment in the Ballast Water Management Convention

The BWMC distinguishes three approaches for assessing an ecological risk from ballast water: 1) the environmental similarity approach; 2) the species biogeographic approach; and 3) the species-specific approach (IMO 2007). The environmental similarity approach is the simplest, being based on the comparison of water salinity and temperature between the ballast water donor and the recipient area. Similar conditions in the donor and recipient area indicate the risk for a species to establish.

The biogeographic approach compares the distribution of species in the donor area and in the recipient area. Risk is based on the occurrence of similar species in both areas.

The species-specific approach is a combination of the previous approaches. This approach includes species-specific data on the minimum requirements of a species to survive, to reproduce, and therefore to spread in both donor and recipient areas. The species-specific approach requires detailed data, since the risk of single species is being assessed (Barry et al. 2008). A detailed approach to risk assessment requires more data, time, and effort. Only relevant aspects and details should therefore be included in a risk assessment (Campbell 2009).

Key factors of ballast water introduction in the North Sea

The key factors in the introduction of aquatic species are derived from the risk approaches according to the BWMC. Preconditions for risk are: 1) species are not transported between the donor and recipient areas by natural pathways, as they are influenced by the hydrography of the sea area; 2) the areas are separated by a barrier of environmental dissimilarity (e.g., a body of water of a different salinity), with conditions in donor and recipient area similar; 3) the areas vary as to species distribution; and 4) shipping acts as a vector of forced transport.

Hydrography of the North Sea

The North Sea is an Atlantic margin continental shelf sea (Figure 1; Van Weering and Kramer 1984). The Dogger Bank separates the North Sea into two hydrologically different parts: 1) in the deep areas north of the Dogger Bank (including the Skagerrak), the water column is vertically stratified by a thermocline during summer; and 2) in the shallow areas of the Dogger Bank, and south and east of the Dogger Bank, the water column is mixed year-round due to wind and tides (Rees et al. 2007; Van Beusekom and Diel-Christiansen 2009). In the northern section, the water inflow from the Atlantic Ocean creates stratification of the water column; this phenomenon causes stable water temperatures (Figure 4; Otto et al. 1990). The southern part is more susceptible to hydrometeorological influences, resulting in turbulent distribution of suspended matter throughout the entire water column and less stable water temperatures. Due to the outflow of Baltic surface water, the water column of the Skagerrak and the surrounding areas deeper than 50 m can be vertically stratified by a halocline (Ten Hallers-Tjabbes et al. 2003). The differences between the two sections lead to differences in species composition and distribution in both sections (Figure 5; Rees et al. 2007). Some species are adapted to the more stable environment in the north, while others are adapted to the more turbulent conditions in the southern part (Rees et al. 2007). We note that this is a primary indication of non-homogeneity in the North Sea.

The very great inflow of water in the northern part, the tides, and meteorological influences together create a counterclockwise current circulation in the North Sea (Figure 4; Otto 1983). The southward current passes along the British east coast, changes direction in the south, due to the inflow of Channel water north of Dover Strait, and then flows northward along continental Europe. The water that first passed along Scotland eventually reaches the

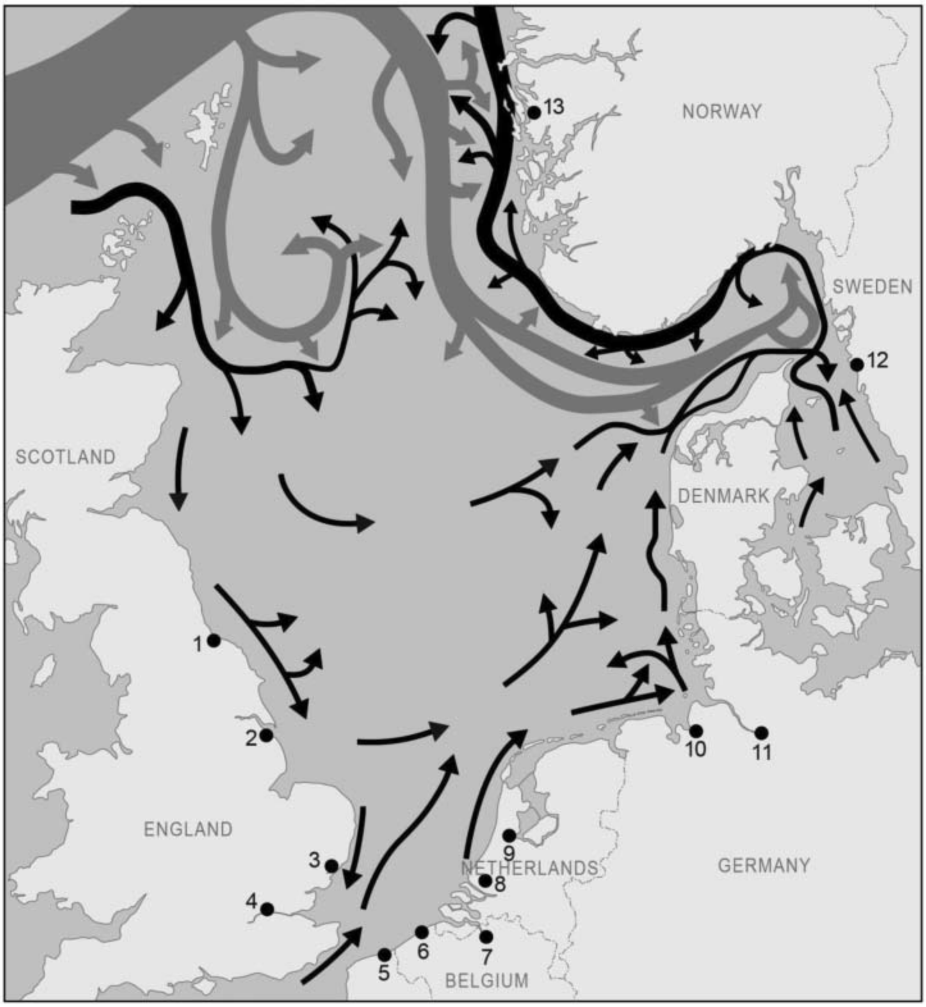

Figure 4. The counterclockwise residual current in the North Sea (black) and the deep water flow from the Atlantic Ocean (gray) (Turrell 1992). The arrow width indicates the magnitude of volume transport. The dark dots are the major North Sea ports. The numbers correspond to the numbers in Table 1.

Danish and Norwegian coasts, but the current will not turn to the west again; it continues north and northeastward, and will not flow back in the direction of Scotland. No natural water transport from east to west occurs, so there is no transport of organisms by natural pathways from east to west.

Conditions of salinity and temperature

Water temperature and salinity are the major factors determining the ability for a species to survive. When the water temperatures and the salinities in the donor and recipient areas show a high degree of similarity, a transferred species is more likely to survive and establish.

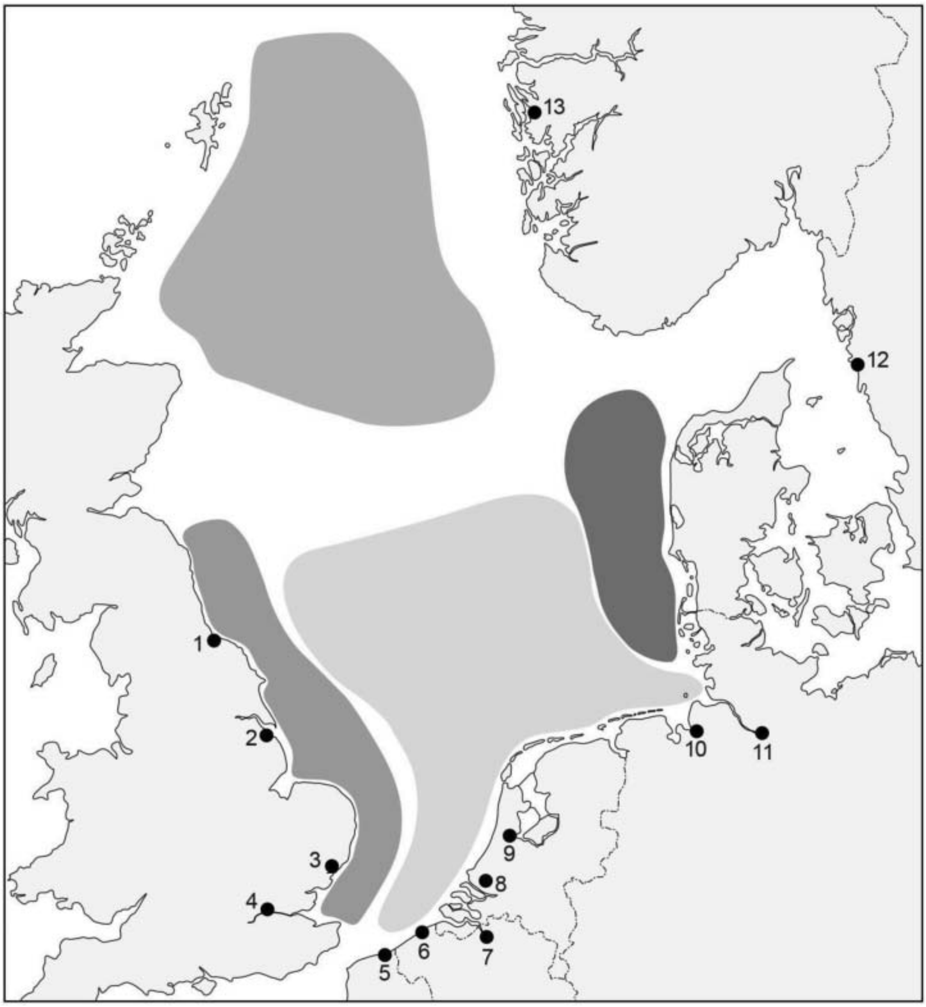

Figure 5. The different benthic habitats in the North Sea. The benthic habitats are determined by the bathymetry, the residual current (see Figures 1 and 2), and the sediment particle size of the North Sea (Eisma 1991; Paramor et al. 2009). The habitats are checked vis-à-vis the distribution patterns of different benthic organisms (Rees et al. 2007; ICES 2008). The variation in gray scale indicates the proposed benthic zones. The dark dots are the major North Sea ports. The numbers correspond to the numbers in Table 1.

Due to the hydrological conditions of the North Sea, the surface and seabed waters of the northern North Sea (I) show a smaller range in seasonal temperature and salinity than the southern North Sea (II) and the coastal zones (Figure 2; Paramor et al. 2009; UKMMASS 2010). Based on temperature, the biogeographical region of the entire North Sea is a cold temperate region (Lüning 1990; Spalding et al. 2007). Cold temperate species survive through the whole North Sea area, and nonindigenous cold temperate species have a chance to survive and establish.

The salinity of the North Sea's central water body is stable and mainly determined by influx of Atlantic waters in the western part of the North Sea (Figures 2 and 4; ICES 2008).

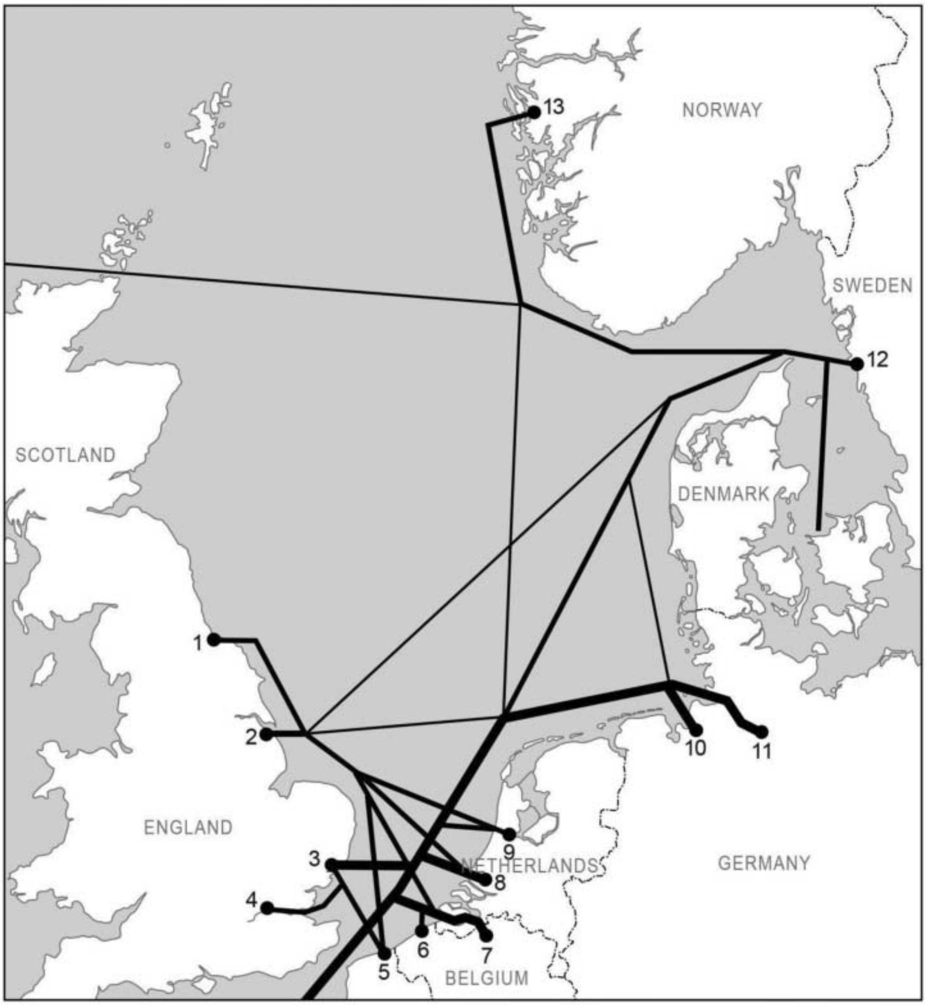

Figure 6. Major shipping links of the Global Network of Shipping projected on the North Sea area (from ESA 2009). Line thickness indicates the shipping density between the different nodes of the network. The dark dots are the major North Sea ports. The numbers correspond to the numbers in Table 1.

The coastal waters in the North Sea area have a higher variation in salinity because of fresh-water runoff from rivers (Otto et al. 1990), which lowers the salinities near the coast. Several major rivers discharge into the southern North Sea. Many of the major North Sea ports (as selected on the basis of cargo transfer) are located in the southern North Sea along rivers or estuaries (Table 1 and Figure 6).

The waters of the fully marine water body of the North Sea act as a barrier to the dispersal of coastal or estuarine species toward other parts of the North Sea, since these species are adapted to lower salinities (Table 3). Due to the tidal conditions, estuarine species are rather well adapted to a wide range of salinities and are able to survive in other areas with a wide range of salinities (Nehring 2006). The salinity conditions in the North Sea indicate a risk of establishment of species transferred by ballast water

Table 3. The range of water salinities in which various groups of organisms are able to survive and to establish (Boesch 1977).

Organisms	Water salinity range (psu)
Freshwater species	0–2
Estuarine endemics	0–15
Euryhaline opportunists	5–21
Euryhaline marine species	12.5 to >30
Marine species	25 to >30

between port areas of similar salinity ranges; such transport circumvents the salinity barrier of the marine water body.

Biota of the North Sea area

Variations in both hydrography and salinity are determinants for species' distribution in the North Sea area, as are the sediment particle size, the nutrient supply (Kaiser et al. 2005; Rees et al. 2007), and the food web structure. The current patterns are a dominant factor determining the passive transport of pelagic planktonic species that follow the residual current (Figure 4).

Currents, however, have a limited influence on the distribution of aquatic benthic species. The boundaries of the main benthic communities in the North Sea are broadly defined by the 50-, 100-, and 200-m depth contours (Figure 1), with the local community structure further modified by sediment type (Figure 5; Callaway et al. 2002; ICES 2008; Kunnitzer et al. 1992). Many of the successful introductions in the North Sea area are those of aquatic benthic species, for example, the zebra mussel (*Dreissena polymorpha*), the Chinese mitten crab (*Eriocheir sinensis*), the American jackknife clam (*Ensis americanus*), and the Australian tubeworm (*Ficopomatus enigmaticus*; DAISIE 2015). Benthic species especially have particular spatial habitats, which occur in some locations in the North Sea but not others (Van Beusekom and Diel-Christiansen 2009). As a consequence, such species can be invasive within the North Sea area. Euryhaline benthic species that tolerate a wide range of salinities (Table 3; Kaiser et al. 2005; Ketchum 1983), which only occur in specific areas in the region, are expected to be able to survive in other estuarine areas around the North Sea.

The introduction of freshwater species also represents high risk vis-à-vis freshwater ports (Table 1). The Thames and other rivers and estuaries in the southeast of England are areas with the highest invasion rates of freshwater species introduced by ballast water from continental ports (Gallardo and Aldridge 2014; Jackson and Grey 2013).

In addition to the environmental match of species donor and recipient areas, propagule pressure is another key factor in the success of species introductions (Haydar and Wolff 2011; Lockwood, Cassey, and Blackburn 2005; Verling et al. 2005). Propagule pressure is a measurement of the number of viable individuals (adults, juveniles, larvae, eggs, cysts, etc.) of a nonindigenous species released into the introduction area (Carlton 1996). It represents the potential for introduction rather than an existent introduction (Johnston, Piola, and Clark 2009).

Successful establishment in a new area requires habitat suitability in terms of the availability of sufficient food, including nutrients, compared to the donor area. In the water column, turbulence is an important factor for nutrient distribution. Turbulent waters create a high organic load of suspended bottom deposits through the water column, which are a primary food source. Estuaries are turbulent areas as a result of the mixing of marine water and freshwater (Wolff 1983). Benthic species in turbulent estuaries can be distributed over the full water column. While loading ballast water, moored vessels easily take in such species, in addition to pelagic species and pelagic stages of benthic species.

Ballast water as vector for nonindigenous species

Propagule pressure may increase due to an increased number of arrival events or an increased intensity of exposure during any one event (Johnston, Piola, and Clark 2009). Ships act as vectors for nonindigenous species. Ballast water is usually loaded in ports located alongside riverbanks or in areas with coastal water conditions. The vessels circumvent the natural salinity barrier for species living in such areas. For water taken in along the eastern shores of the North Sea by ships destined for the Great Britain, the residual current barrier is circumvented as well.

Most ports have a limited water depth, a high turbulence, and a high concentration of suspended sediments as a result of passing ships, and the tidal mixing of marine water and freshwater (Wolff 1983). Consequently, ships are likely to load sediments, and benthic and pelagic species, even when a high-positioned seawater inlet chest is used.

Transfer potential is a function of the transit time of the ship. Many organisms will die in the dark ballast water tanks after a minimum of three days; only a few individuals still live after 10 days (Gollasch et al. 2000). Sailing times between the major North Sea ports are often less than three days (Table 2), indicating a high survival rate of species in the tanks. Some species are highly resistant to in-tank conditions. Benthic species, microalgae, and bacteria are especially able to survive a voyage; the first group does so by settling in the sediment in the tank (Radziejewska, Gruszka, and Rokicka-Praxmajer 2006).

The transfer potential is also determined by the released volume, the release frequency, and the concentration of individual species (Dunstan and Bax 2008). The frequency of ballast water release is recorded by the global shipping network. The global shipping network describes the links between ports worldwide as a function of the frequency of visits by ships (Kaluza et al. 2010; Keller et al. 2011).

An indication of the volume can be derived from the specific types of vessels sailing between specific ports. Different ship types have different ballast water demands. Highly frequently sailed routes with short duration times may present an indication of higher risk of the introduction of species.

Available risk models

Modeling the risk of species introduction is the proper tool for evaluating the risk associated with granting BWM exemptions. Models are limited to modeling the likelihood of an introduction, of course, since the impact of a species in a new area is hard to predict.

The risk of an introduction due to ballast water transport is mainly described by those key factors that have already been discussed in the previous sections. As an approach to modeling for the assessment of risk in the North Sea, we propose including the hydrographical and abiotic conditions, the biota, and the transport vector.

We will evaluate two actual models for the North Sea area, DUE Innovator II (Stelzer 2010) and GETM_ERSEM (NIOZ 2015).

Abiotic modeling

The gradients of salinity and temperature across the area are the key factors for abiotic modeling. The risk is based on similarities or differences in the physical conditions between the donor and recipient areas for the ballast water. The model has to include the water currents in the area in order to explain the natural transport of species across that area.

The DUE Innovator II model calculates the risk of BWE in the North Sea, based on abiotic conditions in the North Sea (Stelzer 2010). This model includes water currents, water salinity, and temperature in a recipient area for BWE (in open seas) that determine the risk for waters downstream to the ballast water release position while performing BWE. The basic principle of the DUE Innovator II model is suitable for the abiotic part of a ballast water risk assessment for the region.

The approach of DUE Innovator II is related to the risk associated with BWE; the model is not intended to describe the risk in terms of acting as a tool for selecting strategies for BWM exemption. The location of ports and the conditions in estuaries are not included in the model.

Biotic modeling

The most challenging aspect in risk modeling is the inclusion of biological determinants and data: the location of a species population, the interaction between species, and the nutrient availability in the different areas in the region. Models like GETM_ERSEM (NIOZ 2015) can be supportive in this respect. GETM_ERSEM is a 3D hydrodynamical ecosystem model of the North Sea. In addition to the hydrography of the area, the model analyzes population dynamics (species growth, decline, and food web structure) of species, which are crucial aspects for predicting the establishment of a new species.

To overcome the problem of lack of data, a list of indicator species can be made according to the consensus method of horizon scanning (Roy et al. 2014). Target groups are distinguished according to planktonic lifetime (short or long planktonic phase) and habitat suitability (habitat specialist or generalist; Forrest, Gardner, and Taylor 2009).

The GETM_ERSEM can model turbulence in the seawater column and can be used to study the effect of turbulence in the water column. Modeling the turbulence in port areas is a requirement for a risk assessment model. The GETM_ERSEM model is not suitable for calculating turbulence in port and river areas.

Vector modeling

None of the models that have been discussed in this study consider the ballast water vector. Some studies indicate that there is no quantitative relationship between the quantity and frequency of ballast water discharges and the number of species introduced (Ruiz et al. 2013). However, the risk of invasive species introductions from ballast water discharge varies between ports, which might well be related to the transit time and therefore the viability of the propagules (NRC 2011; Ruiz et al. 2013).

The intended model aims to calculate the amount of viable individuals of each species that will be released in the recipient area. The yearly released volume per ship in a recipient port is a function of the visiting frequency and the volume of ballast water transferred per voyage. The concentration of viable individuals in the ballast water released can either be calculated by a stochastic analysis of the decline of a species population during the voyage or by using species-specific information about its ability to survive in ballast tanks.

Discussion

Attitude in the shipping sector

Two-thirds of the respondents to our questionnaire are aware of the risk of ballast water transport concerning species introduction. The majority of them say that it is clear what the ways are for performing BWM on their vessels (Figure 3). For the North Sea area, however, ship owners argue that exemptions from the BWE/BWM requirements should be granted because they consider the North Sea to be one ecological zone (Figure 3). They also argue that sailing time is too short to perform BWM. Although ship owners believe that exemptions for the North Sea area should be granted, some already anticipate BWMC. Two-thirds of the questioned ship owners have prepared their vessels for performing BWM (Appendix A).

We do not accept the proposition that the North Sea is one ecological zone. The North Sea is not homogeneous. Salinity is an abiotic key factor that differs between ports (Figure 2) as well as within ports (Table 1). This salinity difference determines the survival of transported species (Table 3). Ballast water discharge in the ports and out in the North Sea could well affect the benthic communities living there (Figure 5).

Modeling ballast water risk indications for the North Sea

This study was performed in order to investigate the feasibility for BWM exemptions in the North Sea area. We discussed how actual models of the North Sea could be helpful in the procedures for granting BWM exemptions. Exemptions are solely granted to those ships exclusively sailing between specified ports within a biogeographical region with similar environmental conditions. The models that are proposed are not specifically designed for use in terms of ballast water risk assessment methods. Specific contents of the models, however, can be used in a new model. Both proposed models, DUE Innovator II and GETM_ERSEM, focus on the hydrography of the North Sea. DUE Innovator II is designed for risk calculation of BWE, based on environmental similarity. The GETM_ERSEM includes biology for the region. The vector ballast water is not included in any of these models, but it can easily be included in a new model in terms of transfer potential. Duration of the voyage is a key factor in modeling the transfer potential.

Performing a ballast water risk assessment with the tools presently in use is complex, and all these assessments need to be executed by specialists. The methods for ballast water risk assessment need to be made more easy to use in order to eliminate the uncertainty involved in the exemptions faced by the shipping industry.

Validity of exemptions

The industry would do well to study the feasibility of installing BWM systems onboard, since the validity of an exemption is limited to up to five years. Exemptions apply to specific routes between permitted ports only. The routes of most ships, however, are not limited to specific ports, except for ferries and ships with long-term contracts. Exemptions are also not as flexible as the availability of cargo in the market. Ships often have to divert to load available cargo at another port that may not be included in the exemption. In that case the vessel would have to apply BWM.

An exemption expires once a vessel is sold and serves other ports. The new owner of a formerly exempted vessel would have to install a BWM system or apply for a new exemption. It is probably more attractive to buy a vessel that is already mounted with a BWM system. If the risk situation in a port changes, an exemption may be withdrawn. An exemption not only requires initial port research for the risk assessment but also regular monitoring to identify risk species turning up during the exemption period. The port sampling protocol described in the joint HELCOM/OSPAR procedure for ballast water exemptions (HELCOM/OSPAR 2013) was tested in the Rotterdam scoping project (GiMaRIS 2014). In the port of Rotterdam, 32 nonnative species were found that were suitable as indicator species (GiMaRIS 2014). The scoping study shows that the monitoring protocol does work effectively (GiMaRIS 2014); however, it is labor-intensive and costly. The study raises the question of the implementation of monitoring results in current exemptions.

Monitoring intensity is also questionable in terms of the scale of the same location concept raised in regulation A3 of BWMC (IMO 2004). We agree with Gollasch and David (2012) that an entire sea cannot be seen as being the same location. Should the same location concept be applied to the smallest practical units, that is, the same harbor or anchorage (David, Gollasch and Pavliha 2013; Gollasch and David 2012), it would still need intensive monitoring as required for port exemptions. Do the monitoring costs and effort outweigh the costs of BWM?

Risk based on North Sea routes

In this study, we found that the risk of the introduction of species, based on the temperature and salinity ranges in the North Sea area, can be high. In most cases, coastal ballast water is transferred to coastal waters in another part of the North Sea area, circumventing the salinity barrier. Passive migration patterns by the residual current indicate that a pelagic species naturally occurring in the waters on the Dutch and German North Sea coasts can pose a high risk of introduction in areas along the British eastern shores. The rate of colonization of freshwater species into the Great Britain, especially the southeast of England, routing from the Netherlands, has accelerated in recent years (Gallardo and Aldridge 2014).

The most high-risk donor ports ranging toward the Baltic Sea are the major hub ports in Europe: Rotterdam (GiMaRIS 2014), Antwerp, Hamburg, and Bremerhaven (Table 1; Gollasch and Leppäkoski 2007). All these big ports along the southeast coast of the North Sea, including Hamburg as the major port of Germany, have a low salinity and highly turbulent water because of river outflow (Table 1 and Figure 2). The threat of secondary spread of invasive species within the North Sea via the international/major hub ports is another issue (Figure 6). We recommend giving routes a prominent place in ballast water risk assessments.

Conclusions

Within the North Sea, ships' ballast water transfers marine organisms with invasive potential. Based on actual models for the North Sea, we have discussed the major parameters that need to be combined and adapted in order to evaluate the exemption for BWM requirements of particular routes in the North Sea.

Exemptions in the North Sea area have been claimed by shipping companies. This paper has investigated the proposition that the North Sea is an ecologically homogeneous zone, where organisms are transported by natural pathways. The hydrological conditions of the North Sea result in an east–west barrier for transport by water currents. Salinity distribution results in a salinity barrier for coast-to-coast transfer of coastal and estuarine organisms, while within the coastal regions salinities remain in a similar range. Various conditions do result in distinct habitats and species distribution patterns within the area, however.

We would note that the North Sea is far from homogeneous in terms of hydrological and biological conditions. The risk of non-indigenous species from other parts of the North Sea being redistributed is considerable, and this is already happening. We conclude that exemptions from BWM are therefore not recommended for the North Sea area. Anticipating the BWMC, ship owners would do well to study the feasibility of installing BWM systems onboard.

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Appendix A. Overview of the result of the questionnaire on ballast water use and management.

Company Specifications Section A .3 .4 .5 .6 / Ballast Water Section B .1 .2 .3 .4

Our company owns/manages	Having vessels regular visiting the North Sea area	Having vessels operating exclusively in the North Sea	Percentage of fleet exclusively operates in the North Sea	Our ships frequently take in and discharge BW*	Problem of BW use is the high risk of species introduction	Impacts of introduced species can get severe	There is no/not a big problem forthcoming from BW use
Oil/product tanker	Y	N		Y	A	A	A
Reefers	Y	N		Y	A	A	D
Multi purpose/roll-on-roll-off	Y	Y	0,9	Y	D	D	A
Multi purpose	Y	N		Y	A	A	D
Chemical/Oil/Container	Y	N		Y	D	D	A
Cruise vessels	Y	N		Y	A	D	D
Patrol vessels	Y	Y		N	D		A
Multi purpose/Container	Y	N		Y	A	A	D
Multi purpose/Container	Y	N		Y	A	D	A
Heavy lift	Y	N		Y	A	A	D
Offshore	Y	Y	0,3	Y	A	A	A
Passenger/roll-on-roll-off	Y	Y	0,3	Y	D	D	A
Passenger/roll-on-roll-off	Y	Y	1	Y	D	D	A
percentage % Yes, Agreed or True	**100**	**33**		**100**	**67**	**50**	**58**

Ballast Water Convention Section C .1 .2 .3 .4 .5 .6

Our company owns/manages	We are aware of existence of BWMC**	This convention is a good solution for BW problems	Measures suggested by BWMC are sufficient	It is good something is being done against BW problems	BWMC has come too late	BWMC has come in time	BWMC has come too early	Measures of the BWMC are redundant
Oil/product tanker	A	A	A	D	A	D	D	A
Reefers	A	A	A	A	D	A	D	A
Multi purpose/roll-on-roll-off	A	A	D	A	D	A	D	D
Multi purpose	A	A	A	A	D	A	D	D
Chemical/Oil/Container	A	N	A	D	D	D	A	A
Cruise vessels	A	A	A	A	D	A	D	A
Patrol vessels	A				A	D	D	
Multi purpose/Container	A	A	A	A	D	D	A	
Multi purpose/Container	A	N	A	D	A	D	D	A
Heavy lift	A	A	A	A	A	D	D	D
Offshore	A	A	A	A	A	D	D	D
Passenger/roll-on-roll-off	A	N	D	A	D	A	D	D
Passenger/roll-on-roll-off	A	A	A	A	A			D
percentage % Yes, Agreed or True	**100**	**75**	**83**	**75**	**42**	**42**	**17**	**42**

Ballast Water Management Section D .1 .2 .3

Our company owns/manages	Clear what ways of BWM could be performed on our vessels	Please specify:	Never heard of it: nobody told us of its existence	Heard of it: until now it had not much attention	Heard of it, but it has not come into force and therefore not clear what to do	Heard of it and read it through, it is unclear why it will help	Heard of it, but it is not applicable to us, therefore no attention	Heard of it and it is clear to us, we studied it ourselves	Heard of it and it is clear to us, someone told us what to do	BWM is (possibly):	Record keeping of BW origin and destination on board	BW treatment	Using as little BW as possible	The exchange of BW	Part of MARPOL legislation
Oil/product tanker	Y		N	N	N	N	N	Y	Y		T	T	NT	NT	T
Reefers	Y		N	Y	Y	N	N	N	Y		T	T	T	T	T
Multi purpose/roll-on-roll-off	Y		N	N	N	N	N	Y	N		T	T	NT	T	T
Multi purpose	Y		N	N	N	N	N	N	N		T	T	NT	T	T
Chemical/Oil/Container	Y		N	N	N	N	N	Y	Y		T	T	NT	NT	T
Cruise vessels	Y		N	N	N	N	N	Y	Y		T	T	T	T	NT
Patrol vessels	N				N						T	NT	NT	T	NT
Multi purpose/Container	Y		N	N	N	N	N	Y	N		T	T	T	T	T
Multi purpose/Container	Y		N	N	Y	Y	N	Y	Y		T	T	NT	T	T
Heavy lift	Y		N	N	N	N	N	Y	Y		T	T	NT	T	NT
Offshore	Y		N	Y	Y	Y	Y	N	N		NT	T	T	T	T
Passenger/roll-on-roll-off	Y		N	N	Y	N	N	Y	N		T	T	T	NT	T
Passenger/roll-on-roll-off	N		N	Y	Y	N	Y	N	Y		T	T	NT	T	T
percentage % Yes, Agreed or True	**92**		**0**	**25**	**42**	**17**	**17**	**67**	**58**		**92**	**100**	**42**	**75**	**83**

Ballast Water Management Application Section E .1 .2 .3 .4

Our company owns/manages	We know what type of BWM will be performed on our ships	We will perform:	Ballast water exchange	Ballast water treatment	no BWM: no reason for it; our ships will be exempted	Our ships already performs some form of BWM	We prepared our vessels for performing BWM already	Some of our costumers demand some way of BWM
Oil/product tanker	A		A	A	D	A	A	
Reefers	A		A	A	D	A	D	D
Multi purpose/roll-on-roll-off	A		A	A	D	A	A	D
Multi purpose	D		A	A		D	D	D
Chemical/Oil/Container	A		D	A		A	A	D
Cruise vessels			D	A	D	D	A	D
Patrol vessels	D							
Multi purpose/Container	A		A	D	D	A	A	D
Multi purpose/Container	A		D	A	D	A	D	D
Heavy lift	A		A	D	D	A	A	A
Offshore	A		A	A	A	A	A	A
Passenger/roll-on-roll-off	D		D	D	A	A	D	A
Passenger/roll-on-roll-off	D		D	A	A	D	A	D
percentage % Yes, Agreed or True	**67**		**58**	**75**	**25**	**75**	**67**	**25**

Ballast Water Exemptions Section F .1 .2 .3 .4

Our company owns/manages	There is no need for performing BWM in areas like North Sea	Although exemption possible, better for environment to do BWM	Exemptions must be granted to ships operating at North Sea	Exemption must be granted, because:	No exemptions must be granted	North Sea is one ecological zone	Time for doing BWM would be too short	No suitable treatment systems are available yet	Other reasons. Please specify:
Oil/product tanker	A	A	A		D	A	A	A	
Reefers	A	D	A		D	D	D		
Multi purpose/roll-on-roll-off	D	D	A		D	A	D	D	
Multi purpose	A	D	A		D	A	A	A	
Chemical/Oil/Container	A	D	A			A	D	D	
Cruise vessels	D	A	A		D	A	A	D	
Patrol vessels	A								
Multi purpose/Container	D	A	A		D	A	A	D	
Multi purpose/Container	A	D	D						
Heavy lift	D	D	A		A	A	D	A	*)
Offshore	A	A	A		A	A	A	A	
Passenger/roll-on-roll-off	A	A	A		D	A	A	D	**)
Passenger/roll-on-roll-off	A	D	A		D	A	A	A	
percentage % Yes, Agreed or True	**67**	**42**	**92**		**17**	**91**	**64**	**50**	

Notes. Y = Yes; N = No
A = Agree; D = Disagree
T = True; NT = Not True
* BW = Ballast water
** BWM(C) = Ballast Water Management (Convention)
*)Rules are not clear
**)BWTS complicated on ferries